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THE EFFICIENCY OF AN USW (ULTRASHORT WAVE) METEOR-BURST COMMUNICATION SYSTEM

(Letter to the Editor)

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I. The experimental meteor-burst radio communication systems known at the present time have a carrying capacity which is considerably lower than the one which can be actually achieved in accordance with the mechanism of meteoric USW propagation. Thus, according to theoretical estimates (for example, /1, 2/), the transmitted frequency band, permissible from the standpoint of multibeam (or multiple) effects, may amount to several dozen kilocycles (kc) during a meteor burst, whereas the signaling speed of the "Janet" telegraph system (3) only amounts to 650 binary elements per second. The quality of meteoric radio channels is also not sufficiently high. For example, in the "Janet" system, the proportion of distorted signs amounts to 0.2% and more. The low efficiency of present meteor-burst communication systems is due both to difficulties in building high-speed terminal equipment for intermittent communications, as well as to the peculiar design of the meteoric radio channel proper.

The use of low-directional antennas is one of the factors hindering the realization of the theoretical carrying capacity in a meteor-burst system and the achievement of high-quality communications. It is known that an effective reflection is caused by meteor tracks formed under various azimuths on the side of the route. The useful sector covers a range of up to 60 degrees and more, depending on the length of the line. The use of high-directional antennas would result in the utilization of only an insignificant portion of meteor bursts, which could eventually lead to a loss in carrying capacity. For this reason, present meteor-burst communication systems utilize, for transmission and reception purposes, antennas with a broad single-or double-lobe pattern (Figure 1), and therefore with a low gain and directive gain. This makes it difficult to obtain high signal/noise ratios and increases the probability of interference with other services. In addition, in case of broad antenna radiation patterns, the use of signals arriving under sharply differing

angles, and consequently, propagated along paths of different length, constitutes a factor which has an unfavorable effect upon a high-speed intermittent communication system. This effect of "multiple path" propagation (which is not identical with the effect of multibeam propagation, in which the same signal arrives simultaneously along different paths) causes the time of propagation to vary from one burst to another. The spread in the signal running time may amount to several milliseconds, and this fact complicates the phasing of terminal equipment and lowers the carrying capacity of the system. In practice, it becomes necessary to perform the phasing operation all over again at the beginning of each meteoric burst, thereby spending part of the useful time on this operation.

II. The literature contains suggestions for regulating antenna bearings in accordance with the daily course of the optimum transmission-reception azimuth (4, 5). Such a regulation of the directivity permits to narrow somewhat the antenna lobes; however, since the angles of arrival of signals have a very blurred (confusing) distribution (6, 7), it is doubtful that this method will make it possible to use lobes narrower than 10-15°.

This system is based on the slow regulation of directivity in accordance with the daily displacement of the mean azimuth derived from a large number of meteor bursts (Figure 1b). However, it is possible to design a meteor-burst communication system with a high-speed regulation of the directivity of narrow-directional antennas in such a way that, during each individual meteor burst, transmission and reception are performed in a direction corresponding to the position of a given meteor track (Figure 1c). In such a system, at the beginning of each burst, the lobes of the transmitting and receiving antennas are contracted (narrowed) and quickly rotated in the direction of the new meteor track. At the same time, depending upon the permissible complexity of antennas and control units, the directivity can be regulated simultaneously in the horizontal and vertical plane, or merely in the horizontal plane. In lines of medium or great length, the major effect will be achieved by regulation in a horizontal plane.

III. Such a system of meteor-burst communication, which for the sake of brevity will be designated as the BPVM system (Bystryy Prostranstvennyy Vybor Meteornogo Sleda - Rapid space selection of meteor track) must exhibit the following substantial advantages:

1. The contradiction between the characteristics of meteor distribution and the required efficiency of antennas is eliminated. There is practically no limitation in regard to the permissible narrowing of the radiation patterns of the transmitting and receiving antennas, which make it possible to design a meteor burst communication system possessing a

high equivalent power and utilizing at the same time a wide scanning sector. This will permit to increase the carrying capacity of the system, improve its stability against outside interferences and interferences caused by multibeam propagation, and will also allow to broaden the frequency range adapted for meteoric communications by the inclusion of higher frequencies, while still using low-power transmitters.

If, for example, by narrowing the antenna lobes, the gain of the transmitting antenna and the directive gain of the receiving antenna are each increased by 6 db (decibels), then the band of the receiving unit can be widened (expanded) 16 times and the initial values of the signal/noise ratio remain unchanged. This will result in a corresponding 16-fold increase in the carrying capacity of the system (not counting the additional advantage resulting from the greater number of utilized bursts in view of the larger size of the scanning sector). The greater efficiency of the antennas can also be utilized in another manner, namely, by operating on the same band and at the same signaling speed, it is possible to increase the effective time factor by prolonging the action of each burst and increasing the number of utilized bursts as a result of the reception of weaker signals. As known, the advisability of using one of these methods depends on the statistical properties of meteoric propagation under given conditions.

2. Variations in the propagation time of signals can be easily compensated on the basis of information on the angles of arrival of these signals.

Compensation of the spread in running time will simplify the phasing of terminal equipment and will also permit to increase the carrying capacity of meteor-burst communications. In particular, it will be possible to avoid a new phasing at the beginning of each meteor burst, and to merely perform a slow correction of the phase error occurring over a long period of time covering a large number of bursts.

3. In case of a high-speed regulation of the directivity of antennas, aimed at creating the most favorable communication conditions for a given route, the directional properties exhibited by the mechanism of meteoric propagation will be utilized in a better manner. This will further reduce mutual interferences with other services and other meteoric communication channels. The latter fact will allow to make a more extensive use of frequency repetition in order to economize the spectrum.

It can be expected that, in view of the above advantages, the use of the BPVM system will permit to expand the potential application of meteor-burst communications to include stationary (fixed) communication

lines, characterized by a heavy load (heavy duty lines) and high requirements on the quality of communications. Although antennas required for such lines will have a somewhat more complicated design, this does not constitute a serious obstacle.

In case of a combined use of a meteor-burst system and a communication system based on the use of ionospheric scattering (2), the BPVM system will allow to make effective use of the complex antennas installed in the ionospheric line unit, which, in view of their sharp directivity, cannot be effectively used in conjunction with meteoric channels of standard design.

The directivity of receiving antennas can be controlled much more easily than that of transmitting antennas. It might be expedient to use a simplified version (modification) of the system, which would involve a regulation of directivity only on the receiving side.

IV. The possibility of designing a meteor-burst communication system with a high-speed regulation of directivity and a constant signal running time is based on the following premises;

1. In the majority of meteor bursts, the level of the reflected signal reaches a maximum value, or a value close to the maximum value, at the beginning of the burst; in case of such signals, the units controlling the directivity of antennas during the early stage of the burst, which are compensated by retarders, operate even in the presence of high signal/noise ratios, thereby ensuring stability of control.

2. In order to ensure an effective operation of the BPVM system, the operating time of control units must be considerably shorter than the duration of the shortest meteor bursts utilized in the system. As a preliminary estimate, on the basis of available data on the relation between the effective useful time factor and the start (trigger) time, the general operating time can be assumed to be equal to about 10 milliseconds. At the same time, the effective band of the control units should be of the order of several hundred cycles, i.e., it must be at least one order narrower than the band of the modulation and manipulation channel. This fact greatly compensates the loss of noiseproof features in the control channel, caused by the fact that broad radiation patterns must be used in this channel, at least during the initial stage of control.

Thus, the characteristic features of the BPVM system are the use of a broad radiation pattern with a narrow band of transmitted frequencies in the control channel, and the use of a narrow radiation pattern with a broad band in the information channel.

3. The overlapping of two meteor bursts occurs very rarely, and, as a rule, the received signal has a quite definite direction of arrival.

4. The same meteoric track is used for transmission and reception, and the directions of transmission and reception required for a given point therefore coincide. This makes it possible to orient the direction of radiation according to the angles of arrival of signals received at the same point.

5. The inconstancy (non-uniformity) of the traveling time of signals can be compensated by measuring the angles of arrival of these signals. Indeed, as can be seen from the geometrical sketch shown in Figure 2, the length of the propagation path is equal to

$$L = a + b = l \quad \frac{\sin \alpha_B}{\cos \beta_A \quad \sin (\alpha_A + \alpha_B)} + \frac{\sin \alpha_A}{\cos \beta_B \quad \sin (\alpha_A + \alpha_B)} \qquad (1)$$

(without taking the curvature of the earth into account), where l is the length of the route; h is the effective altitude of the reflecting sector of the meteoric track; α_A and α_B are the azimuths, and β_A and β_B are the elevations of the reflecting track sector, observed from points A and B respectively. In case of a given value of l, the right side of formula (1) depends only on the angles, whereby only two angles out of four are independent angles, since angles α_A, α_B, β_A, and β_B are tied together by two relations, for example:

$$\frac{\operatorname{tg} \beta_A}{\operatorname{tg} \beta_B} = \frac{\sin \alpha_A}{\sin \alpha_B}$$

$$\operatorname{tg} \beta_A \quad \frac{\sin \alpha_B}{\sin (\alpha_A + \alpha_B)} = \frac{h}{l}$$

The first relation is a purely geometrical relation, while the second one reflects the fact that, during meteoric propagation, all reflections occur in a relatively thin layer, located at a definite altitude ($h \doteq 100$ km), and therefore the magnitude h/l is approximately constant for a given line.

In terms of elevation, L can be expressed by the formula:

$$L = h \left(\frac{1}{\sin \beta_A} \qquad \frac{1}{\sin \beta_B} \right) \qquad (2)$$

Thus, for each given route, the length of the propagation path L, and consequently, also the propagation time of signals τ_p, is determined uniquely with a certain approximation by the values of any two angles out of the four angles α_A, α_B, β_A, and β_B. In order to determine τ_p, it is sufficient, for example, to know the two azimuths α_A and α_B, or the azimuth α and the elevation β of one point. Therefore, by introducing into the system the additional time lag τ_ℓ of the signals, which is related in a definite manner to these two angles, it is possible to find the total traveling time of the signals through the channel, which remains approximately constant for all meteor bursts:

$$\tau = \tau_p + \tau_\ell \approx \text{const.}$$

The selection of angles which are most convenient for controlling the additional time lag depends on the length of the route, on the statistics of the angles of arrival, on the resolving power of the antennas in a horizontal and vertical plane, and on the technical potentials of the equipment. The use of elevation angles is only expedient in case of short routes, if large angles β are frequently observed.

When the directivity is regulated only in the horizontal plane, the azimuths α_A and α_B are only determined in the system. In this case, in order to find the necessary additional time lag τ_ℓ, a mutual exchange of information on azimuths between parties is, generally speaking, necessary, as can be seen from the structure of formula (1). If, on the other hand, the system also contains indicators of elevation angles, then, as can be seen from formula (2),

one can rely at each point only on the elevation, which is determined at a given point, and an exchange of information concerning angles is no longer necessary. However, in order to obtain the necessary accuracy, it might be necessary, even in this case, to utilize the information on azimuths to determine the required time lag, although this can be done without any exchange of information.

In case a lower accuracy of compensation proves to be satisfactory, it is possible, particularly in case of long routes, to simply estimate the necessary time lag according to the azimuth at each separate point, by introducing a time lag both at the transmitting and receiving end of the channel independently, without exchanging information on azimuths. This is possible in those cases, when the right side of formula (1) can be expressed with the necessary accuracy as a sum of two functions, whereby each of these functions depends only on one of the azimuths:

$$L \approx f(\alpha_A) + f(\alpha_B)$$

Other variations and simplifications are also possible.

In case of a stricter approach to the problem, when the curvature of the earth is considered, the geometric aspect of the problem becomes much more complicated; however, the basic principles mentioned above retain their validity and may be summarized as follows. The path length, and therefore the traveling time of the signals, are determined by two out of four angles of arrival; if only the azimuth is measured in each point, then a mutual exchange of information on azimuths is necessary in order to determine the traveling time; when the elevation is measured, no exchange of information is required; information on one azimuth at each point, without any exchange of information, might be sufficient for an approximate (rough) estimate of the traveling time.

The time lag (delay) of signals can be estimated directly by measuring their traveling time. However, under the conditions prevailing in meteor-burst communications, a single-valued (unambiguous) determination of the time lag based on the direction of arrival of reflected signals may prove to be a faster procedure in case of equal noiseproof features. The combined use of both methods is possible, namely a rough estimate of the travel time based on the angles of arrival, and a more accurate estimate based on a temporary (or time) indication.

29 May 1959

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FIGURE APPENDIX

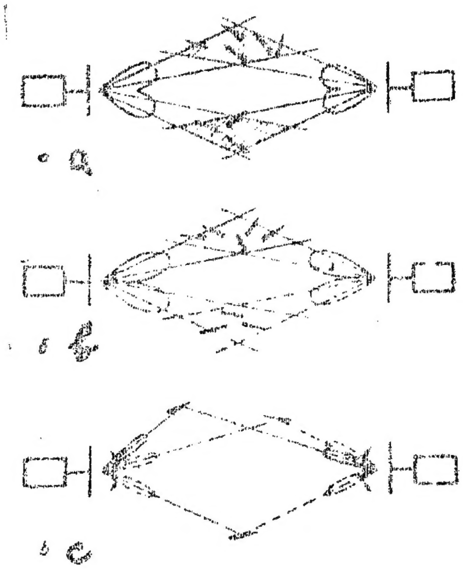

Figure 1.

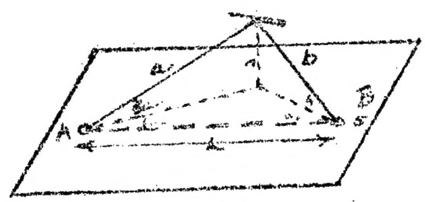

Figure 2.

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